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Procedia Engineering 111 (2015) 364 – 370

**Procedia
Engineering**www.elsevier.com/locate/procedia

XXIV R-S-P seminar, Theoretical Foundation of Civil Engineering (24RSP) (TFoCE 2015)

Multiple-criteria analysis of plasterboard systems

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Abstract

Multiple-criteria analysis methods are a useful tool for decision making support in everyday engineering practice. They turn out to be especially helpful when one considers numerous variants described by many parameters, such as commercially available drywall systems - plasterboard partition walls, claddings and suspended ceilings. In this study four methods of multiple-criteria analysis are investigated (weighted sum, weighted product, ideal point and PROMETHEE II) and 7 normalization algorithms (vector, Manhattan, maximum, Weitendorf linear, Jüttler-Korth linear, Peldschus nonlinear, Zavadskas and Turskis logarithmic) and their influence on the rankings obtained for 5 groups of products: plasterboard partition walls without fire resistance, EI30 partition walls, hard partition walls, suspended ceilings and ceiling claddings. The study shows high sensitivity of the commonly used methods to input data normalization algorithms and indicates the need for a cautious approach to the results obtained by them.

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Peer-review under responsibility of organizing committee of the XXIV R-S-P seminar, Theoretical Foundation of Civil Engineering (24RSP)

Keywords: Multiple-criteria decision analysis; Multiple-criteria decision making; Normalization; Plasterboard; Partition walls; Drywalls; Suspended ceilings

1. Introduction

Decision making is a part of everyday life. When we choose from among the various possibilities, we're wondering which one would be best. To define the "best possible" turns out to be problematic, however. Restricting to a single criterion, which most often is the price, and ignoring the complexity of the issue could lead to selection, which, taking into account the other aspects of the situation, would be considered suboptimal. The most famous

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example of this problem in the engineering environment is public procurement. Awareness of the need to take into account more aspects of decision-making situations gave rise to multiple-criteria decision analysis. Today it is a rich and ever-evolving science, in which a number of methods have been developed and tested.

Decision support is useful especially when we choose from among numerous variants, each of which is described by a large number of parameters. We have to deal with such a situation in the case of drywall. It is hard to imagine modern construction without ubiquitous plasterboard walls, ceiling and wall coverings and suspended ceilings. Manufacturers offer dozens of system solutions, which differ in the materials, dimensions, mass, soundproofing, construction details and the price. Multiple-criteria analysis of the market can help you make rational choices and outright express decision-making objectives and algorithms, which usually remain secret in the case of informal, intuitive decision making[4].

Part of the decision-making process, which in practice defies the usual conscious reflection, is bringing the parameters that describe the solution expressed in different units and scales to common, comparable numeric range. This step, called normalization, even though it is only an introduction to the calculation, however, may have significant impact on its [calculation's] result. In this paper we will look closer at this influence[3].

2. Choice of multiple-criteria decision analysis methods

2.1. The weighted sum method

This is the easiest way to take into account more than one decision-making criterion. It involves the creation of the so-called synthetic criterion –multiple-attribute utility functions in the form of a weighted sum of variant ratings obtained by different criteria. Weights are here synonymous with weights specifying the relative importance of the variants for the decision maker

2.2. The weighted product method

This method can be interpreted as a modification of the previous method, in which the sum has been replaced by the product, and multiplying by the exponentiation to the desired power. Due to the properties of multiplication, this method requires a normalization algorithm, of which the output values are greater than 0.

2.3. The ideal point method

Paper Analysis by this method starts from multiplying rows of the normalized solution matrix with weights vector. The obtained solution matrix takes into account the relative importance of the criteria for the decision maker.

We then create the theoretical "ideal variant", which in each criterion achieves the best score, which managed to reach any of the variants of decision-making. For the "cost" type criteria it will mean the smallest achieved parameter values.

In the same way we create a theoretical "anti-ideal variant" (the worst), which in each criterion achieves the score achieved by the worst variant in this. For the "cost" type criteria it will mean the highest achieved parameter values.

For each of the variants we can count its distance – in the Euclidean space – from ideal and anti-ideal solutions.

A measure of the quality of variant when taking into account multiple criteria becomes its relative distance from the ideal solution: the smaller the value, the closer the variant is to the ideal, and therefore the better.

2.4. PROMETHEE II

And PROMETHEE (Preference ranking organization method for enrichment evaluation) is a method from outranking methods group, invented in 1985 by Brans[1]. Version I allows for partial order of variants, and considered here version II – for building a ranking through total order of variants.

PROMETHEE introduces a function of preference with codomain $[0, 1]$, expressing the degree of preference for variant a in relation to variant b by the decision maker, separate for each criterion and depending on the difference between ratings of variants a and b for a given criterion:

where () is a free parameter (or set of parameters) of this function. Brans [1] suggested 6 preference functions, dependent on at most two free parameters. The author decided to use quasi-criterion with one parameter, modified due to the use of the “cost” criteria:

To each pair of variants (a, b) we assign preference index equal to the quotient of the preference function of variant a in relation to variant b for all the criteria and the number of criteria 1:

To each variant we assign then preference flows – outbound and inbound:

Finally we build variant ranking by ordering them from highest to lowest net preference flow:

3. The issue of the input normalization

Put Variants taken into account when making the decision are described by many parameters. Some parameters can be subjective ratings, expressed in nominal scale or ordinal scale with arbitrarily adopted range (for example, from 1 to 5). Others are objective, measurable characteristics, such as weight or thickness. Due to the different criteria, ratings are expressed in different units and at different scales, and their numerical values can vary by orders of magnitude. Direct comparison is not possible. Most of the methods of multiple-criteria decision support require an initial introduction parameters to one scale; usually in intervals (0, 1), [0, 1), (0, 1], [0, 1] and (0, ∞). This process is called normalization.

Impact of data matrix normalization on the results generated by the multiple-criteria decision support methods has been tested by many authors [2]. Zavadskas and Turskis in [7] list the most commonly used algorithms for normalization together with the new, original method of logarithmic normalization. Extended in respect to [8] list of normalization methods, which were examined in this paper, is included in the following table.

Table 1. Normalization methods considered in this paper

No.	Normalization method	Formula	Codomain for $A_{0ij} > 0$
1	Vector (Euclidean)	$A_{veij} = \frac{A_{0ij}}{\sqrt{\sum_i (A_{0ij})^2}}$	(0, 1)
2	Street (<i>Manhattan</i>)	$A_{manij} = \frac{A_{0ij}}{\sum_i A_{0ij} }$	(0, 1)
3	Linear (maximum)	$A_{tmaxij} = \frac{A_{0ij}}{\max_{1 \leq k \leq m} A_{0kj}}$	(0, 1]
4	Weitendorf's linear	$A_{lWij} = \frac{A_{0ij} - \min_{1 \leq k \leq m} A_{0kj}}{\max_{1 \leq k \leq m} A_{0kj} - \min_{1 \leq k \leq m} A_{0kj}}$	[0, 1]
5	Jüttler-Körth's	$A_{JKij} = 1 - \left \frac{\max_{1 \leq k \leq m} A_{0kj} - A_{0ij}}{\max_{1 \leq k \leq m} A_{0kj}} \right $	(0, 1]
6	Peldschus' non-linear	$A_{nlp_{ij}} = \left(\frac{A_{0ij}}{\max_{1 \leq k \leq m} A_{0kj}} \right)^2$	(0, 1]
7	Zavadskas' and Turskis' logarithmic	$A_{lnzT_{ij}} = \frac{\ln A_{0ij}}{\ln \left(\prod_i A_{0ij} \right)}$	[0, 1)

4. Research methodology and the materials used

On the basis of commonly available materials of the manufacturer [5] there were separated and chosen 5 drywall system solution groups with similar fields of application: separation walls EI15 or without fire resistance, EI30 walls, partition walls, suspended ceilings without fire resistance and ceiling linings without fire resistance. From 6 to 14 products were investigated in each of these solution groups.

For each group of products there were established from 4 to 7 rating criteria. To increase the readability calculations it was decided on the consistent use of only the “cost” criteria, in which the best score is the smallest value of the corresponding parameter.

The **complexity** is defined as the sum of the number of different system components and additional boards, when more than one is used. This criterion is applied to the ceiling linings and suspended ceilings. The greater complexity of the solution means a longer execution time, greater requirements for training employees and higher likelihood of errors in the execution.

Sound conduction is defined starting from the definition of the sound intensity level: (a) as (a) where $R = R'A1$ (for wall and ceiling lining) or $R = R'W$ (for suspended ceiling). Constant factor was introduced in order to ensure that the evaluation of all the variants in this criterion will be greater than 1 to ensure correct normalization by Zavadskas’ and Turskis’ logarithmic method. Specified in catalogue ceiling lining’s, wall’s or ceiling’s acoustic insulation, which is the basis for the calculation, describes the relative change in the intensity of the sound. The need to convert acoustic insulation for so defined sound conduction is due to the use of the “cost” criteria in this paper.

The **density distribution of profiles** defined as , where $r_{x,max}$, $r_{y,max}$, is the maximum spacing of ceiling profiles (expressed in millimeters), respectively: laterally to the length of the slabs and the mains. The more densely spaced profile, the higher the probability of collision with elements placed in the ceiling and a larger execution time.

The **density distribution of hangers** are defined as, where r_x is expressed in millimeters maximum distance between ceiling hangers. The more densely spaced hangers, the harder it is to arrange on-ceiling installations and put there devices.

The **thickness** expressed in millimeters was deemed negative criterion (such as “the cost”), because the superstructure with greater thickness reduces the dimensions of the production premises. It would be otherwise in the case of not included in this paper installation walls, of which thickness is an important parameter in determining the possibility of placing in them tubes and racks.

The **mass** of the walls, or ceiling linings, expressed in kg/m^2 is of great importance for renovations and repurposing of buildings, especially older ones, when you must reckon with the limited bearing capacity of the structure.

Net price in PLN/ m^2 is a clear decision criterion, bypassing which leads to suboptimal resource allocation.

A collection of the considered variants, along with their parameters, is saved in the A_0 matrix with dimensions $m \times n$, where m rows correspond to the variants, and the n columns to the decision-making criteria. $A_{0i,j}$ is the value of j -th parameter (rating according to j -th criterion) in i -th solution. Using the 7 input normalization methods – vector, street, maximum, Weitendorf’s linear, Jüttler-Körth’s linear, Peldschus’ non-linear, Zavadskas’ and Turskis’ and logarithmic – we obtain normalized matrix of variants A . Then we take the vector of weights W_j , describing the relative importance of individual criteria for the decision-maker. For the sake of transparency and simplification of calculations we assume that the sum of the weights is equal to 1. Having the 7 normalized matrices of variants A and weight vector W , we can use one after another all 4 methods of multiple-criteria decision support – weighted sum, weighted product, the ideal point, and PROMETHEE II – to create ranking of variants (Weitendorf’s linear normalization method brings down the scores to the bounded interval $[0, 1]$, which makes application of the weighted product method pointless), ordered from most to least preferred with the given combination of methods for the multiple-criteria analysis and data normalization algorithm.

Obtained rankings were analyzed for their dependency on the algorithm used for normalization and on multiple-criteria decision support methods. Identical forms of rankings repeating within a combination were marked with the same color, in order to facilitate the observation of patterns among dependencies.

5. Separation walls without fire resistance

Separation walls without fire resistance or low-resistance (EI15) have sheathing of "classic" plasterboard, in the case of products of the Rigips company the Rigimetr panels are 12.5 or 15 mm thick. Use of double or triple sheathing improves sound insulation, but increases the weight and production cost of the wall.

Table 2. Separation walls without fire resistance – characteristic

No.	RIGIPS system number	Short system description
1	3.40.01	Separation wall on structure from profiles CW 50 and UW 50 with single sheathing of plasterboard RIGIPS RIGIMETR 12,5mm thick.
2	3.40.02	Separation wall on structure from profiles CW 75 and UW 75 with single sheathing of plasterboard RIGIPS RIGIMETR 12,5mm thick.
3	3.40.03	Separation wall on structure from profiles CW 100 and UW 100 with single sheathing of plasterboard RIGIPS RIGIMETR 12,5mm thick.
4	3.40.031	Separation wall on structure from profiles CW 100 and UW 100 with double sheathing of plasterboard RIGIPS RIGIMETR 12,5mm thick.
5	3.40.131	Separation wall on structure from profiles CW 100 and UW 100 with double sheathing of plasterboard RIGIPS RIGIMETR 15mm thick.
6	3.40.132	Separation wall on structure from profiles CW 100 and UW 100 with triple sheathing of plasterboard RIGIPS RIGIMETR 15mm thick.
7	3.40.141	Separation wall on structure from profiles C 250 with sheathing of plasterboard RIGIPS RIGIMETR 15mm thick.
8	3.40.142	Separation wall on structure from profiles C 250 with sheathing of plasterboard RIGIPS RIGIMETR 15mm thick.

Table 3. Separation walls without fire resistance – parameters

No.	RIGIPS system number	Board count	EI fire resistance class[min]	Acoustic insulation R.A1[dB]	Maximum height[mm]	Thickness [mm]	Mass [kg/m ²]	Net price for 1 m ² [PLN/m ²]
1	3.40.01	1	15	38	3000	75.00	26	32.82
2	3.40.02	1	15	42	4500	100.00	26	34.66
3	3.40.03	1	15	44	5000	125.00	26	36.79
4	3.40.031	2	15	44	6500	125.00	26	42.10
5	3.40.131	2	n/a	74	10500	410.00	75	129.20
6	3.40.132	3	n/a	78	11000	440.00	100	171.31
7	3.40.141	1	n/a	70	16500	441.00	70	196.48
8	3.40.142	1	n/a	70	17000	471.00	95	229.94

Table 4. Separation walls without fire resistance – values of criteria rating

No.	RIGIPS system number	Sound conduction	Thickness [mm]	Mass[kg/m ²]	Net price for 1 m ² [PLN/m ²]
1	3.40.01	16848.93	75.00	26	32.82
2	3.40.02	6309.57	100.00	26	34.66
3	3.40.03	3981.07	125.00	26	36.79
4	3.40.031	3981.07	125.00	26	42.10
5	3.40.131	3.98	410.00	75	129.20
6	3.40.132	1.58	440.00	100	171.31
7	3.40.141	10.00	441.00	70	196.48
8	3.40.142	10.00	471.00	95	229.94

It was assumed that the decision-maker is investor, who cares equally on acoustic comfort and limiting costs. Implementation limits such as a wish to use possibly thin and light walls are less significant.

Table 5. Separation walls without fire resistance – criteria weights

Criterion	Weight
Sound conduction	0.40
Thickness	0.10
Mass	0.10
Net price for 1 m ²	0.40

Table 6. Separation walls without fire resistance – rankings in relation to multiple-criteria scoring method and normalization algorithm

Normalization method	Weighted sum method	Weighted product method	Ideal point method	PROMETHEE II method
Vector (Euclidean)	3>4>2>5>6>7>8>1	6>5>7>8>3>4>2>1	3>4>5>6>2>7>8>1	1 >3>2>5>4>6>7>8
Street (<i>Manhattan</i>)	3>4>5>2>6>7>8>1	6>5>7>8>3>4>2>1	5>3>4>6>7>8>2>1	1 >3>2>5>4>6>7>8
Linear (maximum)	3>4>2>5>6>1 >7>8	6>5>7>8>3>4>2>1	3>4>2>5>6>7>8>1	1 >3>2>5>4>6>7>8
Weitendorf's linear	3>4>2>5>1 >6>7>8	-	3>4>2>5>6>7>1 >8	1 >3>2>5>4>6>7>8
Jüttler-Korth's	3>4>2>5>6>1 >7>8	6>5>7>8>3>4>2>1	3>4>2>5>6>7>8>1	1 >3>2>5>4>6>7>8
Peldschus'	3>4>2>5>6>1 >7>8	6>5>7>8>3>4>2>1	3>4>2>5>6>7>1 >8	1 >3>2>5>4>6>7>8
Zavadskas' and Turskis' logarithmic	6>5>7>8>3>4>2>1	6>5>7>8>3>2>4>1	6>5>7>8>3>4>2>1	5>1 >3>2>6>4>7>8

if The weighted sum method and ideal point method gave consistent results in terms of 6 classic algorithms for normalization, indicating the 3rd variant as optimum and 4th as the second best. The exception here was the combination of the ideal point method and street normalization, where as the best was considered 5th variant, which in most combinations was ranked mediocre. The weighted product method gave consistent results across all normalization algorithms, however, they were different from the other 3 methods – as the optimal, 6th variant was indicated, which other methods placed next to 5th variant, near the middle of the ranking. Surprising results of

analysis gave the PROMETHEE II, which for 6 classic normalizations generated identical rankings, in which the best was, considered to be the worst or average by other combinations of methods and algorithms, the 1st variant.

The Zavadskas' and Turskis' data normalization method caused the weighted method and ideal point method generated same rankings as the product weight method. The combination of the Zavadskas-Turskis' normalization and PROMETHEE II method gave an ordering similar to others obtained by this method, with one difference – 5th solution jumped into the first place in the ranking.

6. Conclusions

Necessary An attempt to compare the methods of multiple-criteria analysis and choose the best of them leads to the well-known in the literature paradox. [6] The choice of the best method in itself is a matter of multiple-criteria decision support. To choose the best method, it would be useful to know it in advance, so as to use it for that choice. The issue is further complicated by the data normalization problem. In practical applications of multiple-criteria decision support no greater emphasis is put on input data normalization, usually simply proposing any of several popular algorithms.

Meanwhile, studies on the impact of the multiple-criteria analysis methods and data normalization algorithms in form of variant rankings in five sets of drywall solutions have shown that, depending on the considered set of the variants, different combinations of multiple-criteria decision support methods and normalization algorithms can give both very consistent and quite divergent results. The differences between the results obtained by different sets of methods and algorithms can be considerable, including even the total reversal of the rankings. PROMETHEE II method is among the least sensitive to the input normalization algorithm change. This is because of how the method works: it compares in pairs the scores of variants according to individual criteria, with the use of thresholds, by which changes of specific score values or their proportions have little impact on the final aggregation of preferences. It can be noticed that the outranking methods in general are, due to how they work, less sensitive to differences in the way of processing the input data. The conceptually simplest methods and through this the most convenient for use by non-experts – weighted sum and the weighted product method – turned out to be the most sensitive to changes in the data normalization method.

Obtained results clearly show that the method of multiple-criteria decision support – just like other ways of the design process automation, such as the finite elements method – can't be treated as a "black box", into which we throw objectives and obtain the results. Supporting decisions with algorithmic methods should always be preceded by a reflection on the limits of the objectives that we make. Engineer standing in front of the problem cannot forget that regardless of the constantly growing opportunities afforded to us by the development of algorithms, the final responsibility for the decision taken will always bear the man.

References

- [1] J. P Brans, Ph. A. Vincke, Preference Ranking Organisation Method: The PROMETHEE Method for Multiple Criteria Decision-Making. *Management Science*, 1985, 31 (6), pp. 647-656
- [2] M. Dytczak, Wybrane metody rozwiązywania wielokryterialnych problemów decyzyjnych w budownictwie. Opole, 2010
- [3] N. Ibadov, J. Kulejewski, M. Krzemiński Fuzzy Ordering of the Factors Affecting the Implementation of Construction Projects in Poland, ICNAAM 2013, 21-27 September 2013, Rhodes, Greece, AIP Proceedings V.1558 p.1298 - 1301
- [4] M. Krzemiński, The selection of construction sub-contractors using the fuzzy sets theory, ICNAAM 2014, 22-28 September 2014, Rhodes, Greece, AIP Proceedings V.1648 p.600005-1 - 600005-4
- [5] Systemy i produkty: Rigips Saint-Gobain [online]. [dostęp 16 marca 2014 r.] Dostępny w Internecie: <http://www.rigips.pl/systemy-rigips.htm>
- [6] E. Triantaphyllou, S. H. Mann, An examination of the effectiveness of multi-dimensional decision-making methods: A decision-making paradox. *Decision Support Systems*, 1989, 5 (3), s. 303-312
- [7] E. K. Zavadskas, Z. Turskis. A New Logarithmic Normalization Method in Games Theory. *INFORMATICA*, 2008, 19 (2), s. 303-314
- [8] E. K. Zavadskas, Z. Turskis. F. Peldschus, Multi-criteria Optimization System for Decision Making in Construction Design and Management. *Engineering Economics*, 2009, 1 (61), s. 7-17